SEMICONDUCTOR DEVICE AND POWER CONVERTER USING THE SAME

BACKGROUND OF THE INVENTION

[0001] The present invention relates to semiconductor devices and power converters using the semiconductor devices and more particularly, to a semiconductor device and a power converter using the semiconductor device, which are suitably used in wide applications ranging from small power equipment such as an air conditioner or a microwave oven to a large power equipment such as an inverter for use in railroad or ironworks.

[0002] An insulated gate bipolar transistor (which will be referred to as IGBT, hereinafter) is a switching element which controls a current flowing between collector and emitter electrodes caused by a voltage applied to a gate electrode. A power range controllable by the switching element is between tens of watts and a level exceeding one hundred thousand watts, and a switching frequency range is also wide and between tens of hertz to hundreds of hertz. In order to make the most of such a feature, the IGBT is used in a broad fields ranging from small power home equipment such as an air conditioner or a microwave oven to large power equipment such as an inverter for use in railroad or ironworks.

[0003] In order to increase the efficiency of a power converter or the like to which the IGBT is applied, the IGBT has been required to reduce its loss and to take various measures.

[0004] The above loss includes a conduction loss, a turn-on loss, and a turn-off loss. A voltage generated between collector and emitter electrodes during ON state of the IGBT is called ON voltage, which is proportional to the conduction loss. For this reason, the ON voltage is used as an index of the conduction loss. Thus, it becomes important for the IGBT to reduce the ON voltage, the turn-on loss, and the turn-off loss.

[0005] FIG. **13** shows a cross-sectional structure of a first prior art. More specifically, FIG. **13** corresponds to a trench insulated gate type IGBT **12** for improving electrical characteristics which is set forth in Paragraph [0056] in JP-A-2000-307116.

[0006] In FIG. **13**, reference numeral **500** denotes a collector electrode, numeral **100** denotes a p layer contacted with the collector electrode **500** with a low contact resistance, **112** denotes an n layer having a carrier concentration lower than that of the p layer **100**, **110** a drift n^- layer having a carrier concentration lower than that of the n layer **112**, **120** a channel p layer, **121** a p^+ layer, **125** a floating p layer, **130** an n^+ layer, **600** an emitter electrode contacted with the p^+ layer **121** and the n^+ layer **130** with a low contact resistance, **300** a gate insulated film, **200** a gate electrode, **401** an insulating film, **501** a collector terminal, **601** an emitter terminal, **201** a gate terminal.

[0007] The IGBT is featured in that a gate width is shortened by thinning out the emitter electrode **600** from the general trench insulated gate IGBT, thus reducing a saturation current. As a result, a current flowing when the IGBT is short-circuited is suppressed with an improved breakdown resistance.

[0008] The IGBT has another feature that part of a Hall current flows through the floating p layer **125** when the emitter electrode **600** is removed and instead the floating p layer **125** is introduced. As a result, a hole concentration in the vicinity of the emitter is increased, a resistance is reduced, and the ON voltage is reduced, which results in reduction of the loss of the IGBT and in reduction of the loss of a semiconductor power converter using the IGBT.

[0009] However, it has been found that the aforementioned IGBT of FIG. **13** has problems which follow.

[0010] The IGBT of FIG. **13** operates as follows when the IGBT is turned ON from its OFF state. In the OFF state, the channel p layer **120** or the floating p layer **125** has nearly the same potential as the emitter electrode **600**, and a voltage between the collector and the emitter is shared by the drift n^- layer **110**. When a desired threshold voltage for forming a channel inversion layer in the channel p layer **120**, electrons are injected from the n^+ layer **130** through the channel inversion layer into the drift n^- layer **110**. This causes the drift n^- layer **110** to modulate its conductivity, so that a Hall current flows from the channel p layer **120** through the n layer **112** into the drift n^- layer **110**, whereby a conduction state is put between the collector and the emitter.

[0011] In the course of the turn-on transition, the floating p layer **125** has a potential higher than the gate electrode **200** during a certain time. This causes the floating p layer **125** is coupled to the potential of the gate electrode **200** through a gate capacity. Further, since a displacement current is passed through the gate capacity, the displacement current causes a voltage to be induced at a gate resistance present between the gate electrode **200** and the emitter electrode **600**, which results in that the potential of the gate electrode **200** is increased even with this induced voltage.

[0012] As a result, the potential of the gate electrode **200** is increased by the floating p layer **125**, so that the injection of electrons and the conduction modulation are accelerated and (dVce/dt) becomes large. This involves such a phenomenon that an overvoltage noise Vp for diodes of paired arms becomes high in an inverter circuit. Since this influence may exceed the rated voltages of the diodes, the IGBT of FIG. **13** is required to take its measure.

[0013] As mentioned above, the displacement current flows through the gate resistance to generate a voltage. Thus, even the gate resistance is made large to control the displacement current, the voltage induced on the gate resistance cannot be sufficiently reduced, and on the contrary, an increase in the turn-on time results in that the switch loss is largely influenced.

[0014] FIG. **14** shows turn-on waveforms for the IGBT of FIG. **13** and reverse recovery waveforms for diodes of paired arms. In the drawing, Vp denotes backward overvoltage noise when the diodes of the paired arms have an anode-to-cathode voltage Vak. The backward overvoltage noise Vp is generated depending upon a collector-to-emitter voltage Vce of the IGBT.

[0015] FIG. **15** shows small-current turn-on waveforms for the IGBT of FIG. **13** and reverse recovery waveforms for diodes of paired arms. The backward overvoltage noise Vp tends to be further increased upon small-current turn-on operation.

[0016] FIG. **17** shows an example of a dependency of Vp to a turn-on current of an IGBT normalized by a rated current. When the IGBT of FIG. **13** is used, there has been observed from experiments and calculations of the inventors of this application a tendency that, as shown by a solid line indicating the structure of a prior art in FIG. **17**, Vp becomes large with a small current and becomes large, in particular, upon turn-on of a small current corresponding to 1/10 to 1/20 of the